THE PEP II INJECTION KICKER SYSTEM

G.C. Pappas, A.R. Donaldson, D. Williams,
Stanford Linear Accelerator Center

Abstract

PEP II or the B Factory consists of two asymmetric storage rings. The injection energy for electrons is 9 GeV, while that for positrons is 3.1 Gev. The bend angle into the high energy ring (HER) is 0.35 m-rad, and the angle into the low energy ring (LER) is 0.575 m-rad. The magnetic length for the HER kicker is 0.85 m, and 0.55 m for the LER kicker. The field produced by the magnet is therefore 123.5 G for the HER, and 132 G for the LER. Each ring has a kicker magnet upstream of the injection line which is used to distort the orbit of the stored beam. An identical magnet downstream of the injection line is used to restore the orbit of the stored beam and inject the incoming beam. The two magnets are driven in parallel by the modulator. The aperture of the magnets is 3.86×3.46 cm (H×V). Therefore the current required to drive the HER is 863 A, while for the LER it is 756 A. The inductance of the magnet is approximately 1.4 μH/m. The current pulse is a critically damped sinusoid with a rise time of less than 300 ns. A kicker system has been designed which can be used for injection of both beams by varying the charge voltage. The modulator uses a conjugate circuit to match the impedance of the magnet, and coupling to the beam chamber.

THE PEP II INJECTION KICKER MAGNET

The PEP II injection and orbit distortion kicker magnets are single turn, H-type magnets, made from blocks of Ceramic Magnetics CMD5005 ferrite. The HER magnet uses 6 C-shaped ferrite blocks which are clamped together with their pole tips facing to form a rectangular aperture. The LER, which is 1/3 shorter, uses only four ferrite blocks. The magnets used for beam abort are identical to the injection kicker magnets[1]. The beam chamber is made from 2.5" inner diameter by 3.0" outer diameter alumina-ceramic pipe, and is coated with 0.3 Ω/square of kovar which was applied by a sputtering process. The length of the ceramic tube is 39.37", resulting in a coating resistance of approximately 1.5 Ω. The bus bars are bonded to the ceramic chamber with indium, and are water cooled to remove the power dissipation of the beam return current in the resistively coated chamber. The ceramic beam chamber supports the weight of the upper bus, and the upper ferrite. EPR rubber is used between the bus bars and the ferrite for mechanical compliance. The ferrite core is then clamped together in an aluminum housing. A cross sectional view of the magnet is shown in Figure 1, while a longitudinal view is shown in Figure 2.

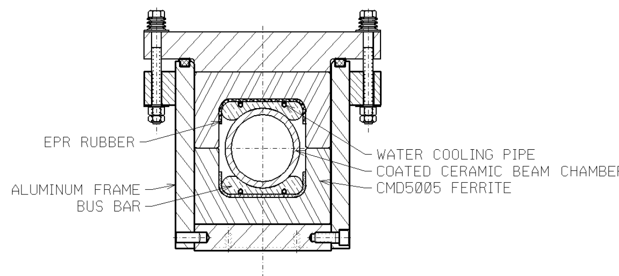

Figure 1. Cross section of the PEP II injection kicker magnet.

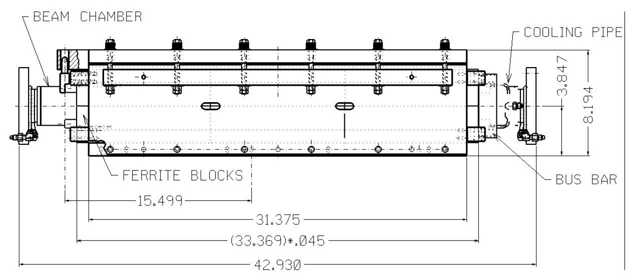

Figure 2. Longitudinal view of the PEP II HER injection kicker magnet.

The electro-magnetic field solver MAXWELL was used to calculate various parameters associated with the magnet. The inductance of the single turn of the magnet was calculated to be 751 nH, the inductance of the beam chamber is 577 nH, and the mutual inductance between the bus bars and the chamber is 556 nH. The capacitance from the bus bars to the aluminum case and the coated chamber is 5 nF. A plot of the field distribution across the middle of the aperture is shown in Figure 3. The driving current for this calculation was 1221 A which results in a magnetic gain of the magnet of 0.139 G/A. The highest electrical field stress point is in the corner where the bus bar separates from the ceramic chamber. The field calculated at this point with a bus bar voltage of 15 kV is 4.7 MV/m. This high field is troublesome, however no electrical breakdown, or corona has been detected in testing.

Work supported by the Department of Energy under contract No. DE-AC03-76SF00515

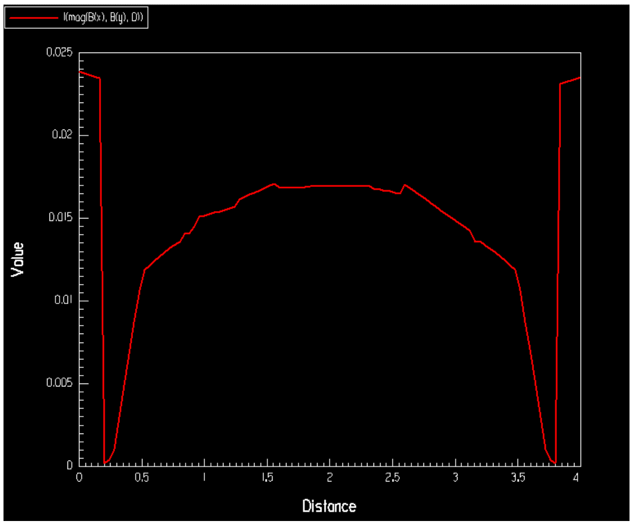

Figure 3. Plot of magnetic field magnitude across the center of the aperture.

The magnet and coated chamber can be modeled as a single turn transformer shown in Figure 4. In this model the bus bar L_1 is replaced with the term L_1-M (90 nH), and the coating inductance L_2 is replaced with the term L_2-M (180 nH), where M is the mutual inductance between the conductors. The resistor is used to model the chamber coating resistance. Using this model it is possible to solve for the effect that the coating has on both the B field rise and fall times, and the peak magnetic field[2]. The results of this analysis are shown in Table 1 for various coating resistances. The nominal rise time for the current pulse was 100 ns for this analysis.

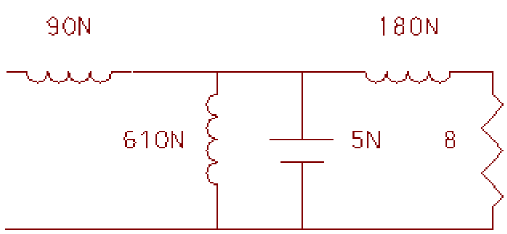

Figure 4. Schematic for single turn transformer model of magnet and beam chamber.

R_c Ω	t µs	B
100	0.3	15.7
0.45	0.34	14.22
0.2	0.38	13.43
0.1	0.44	11.48

Table 1. Pulse rise time and peak B field for various chamber coating resistances.

THE PEP II INJECTION KICKER MODULATOR

The modulator for the PEP II injection system uses a capacitor discharge circuit to form a pulse which has a sinusoidal rise, and an exponential decay. A schematic of the modulator is shown in Figure 5. A 20 kV, Electronic Measurements, Inc. capacitor charging power supply, model 402L, is used for the high voltage source. The switch tube used is a EG&G HY5, single gap, ceramic envelope, hydrogen thyratron.

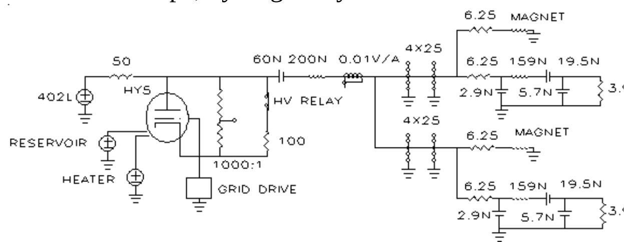

Figure 5. Schematic of the PEP II, HER injection kicker system.

Four parallel lengths of Time Microwave AA8481 cable connect the modulator to the magnet. The impedance of the AA8481 cable is 25 Ω, for a 6.25 Ω connection to the magnets, with the injection kicker magnet and the orbit distortion magnet being driven in parallel. The lengths of the cable runs for the magnets are 189.5 ft for the HER injection kicker, 254 ft for the HER orbit distortion kicker, 478.1 ft for the LER injection kicker, and 260 ft for the LER orbit distortion kicker.

It is possible to use a conjugate circuit in parallel with the magnet which makes the magnet load and matching resistor appear to be purely resistive, and therefore minimize reflections[3]. In the conjugate circuit, the inductors, capacitors, and resistors from the magnet model shown in Figure 4 are replaced with capacitors, inductors, and resistors, respectively. The values of the components in the conjugate circuit can be calculated from the characteristic impedance of the cable, $Z=\sqrt{\frac{L}{C}}$, in the case of the inductor and capacitors, and $R_{con}=R^2/Z$, where R is the resistance of the chamber coating. The modulator, magnet with beam chamber, and the conjugate circuit were modeled in SPICE. The results of this analysis are shown in Figure 6. Here the charge voltage was 15 kV.

OPERATION OF THE HER INJECTION SYSTEM

The HER injection kicker system has been fully tested and installed. Figure 7 shows the magnet current, and the magnetic field integrated over the length of the magnet. The area of the probe used was 1.275×10^{-3} m^2, therefore the field at 1200 A is approximately 149 G, or 124 mG/A.

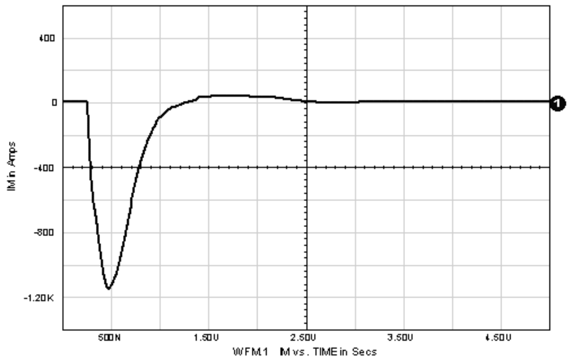

Figure 6. SPICE simulation of the PEP II HER injection kicker system, showing magnet current.

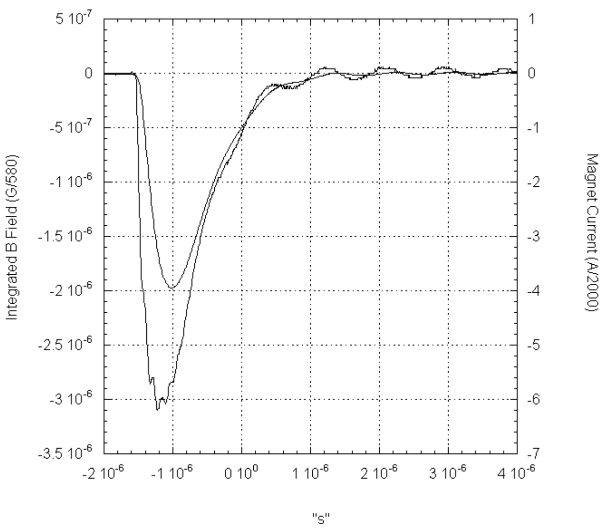

Figure 7. Magnet current and integrated magnetic field.

From Figure 7, it is seen that the rise time of the current pulse is approximately 200 ns, while the rise time of the integrated magnetic filed is approximately 400 ns. This discrepancy is close to that predicted by the analysis shown in Table 1. Several attempts where made to increase the rate of rise of the current pulse. Circuit, and magnet connection inductances were reduced as much as possible. The overall circuit inductance with the magnet shorted was measured to 810 nH. The load, which is made from sixteen parallel, twelve inch long by one inch diameter, cylindrical, Cesiwed, type AS resistors, contribute the majority of this inductance, approximately 500 nH. A new load using disk type resistors with a coaxial return is planned.

In order for the PEP II injection scheme to work properly, the magnetic field in the injection kicker magnet and the field in the beam distortion magnet need to be identical. Because the cable runs to the magnets are different, any reflection from the magnets need to be minimized. Figure 8 shows the magnet currents for the HER injection and beam distortion magnets, and clearly shows that the injection magnet and the orbit distortion magnet are well matched.

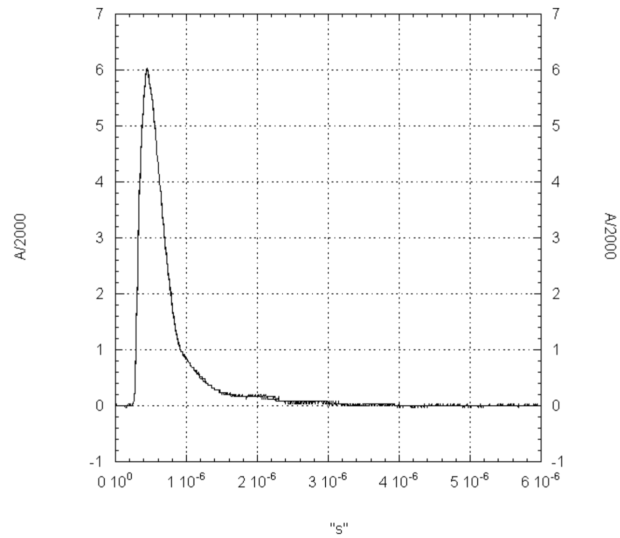

Figure 8. Overlay of HER injection and beam distortion magnet currents.

CONCLUSIONS

A modulator and magnet have been constructed which are capable of providing the pulsed magnetic field consistent with the PEP II injection kicker requirements. Only a proto type modulator has been built and installed for the HER. Two new modulators are currently being fabricated. The system has not been fully commissioned with beam.

ACKNOWLEDGMENTS

The authors would like to thank Dick Cassel, for his encouragement to build a H magnet instead of a C magnet, which leads to a lower induced voltage on the beam chamber. Also thanks to Ed Daly, Hank Atilles, and Mike Robertson for their help with the mechanical design and assembly of the magnet, and Pat Banglos, Joe Olszewski, and John Krzaszczak for their electronic technical support, and installation.

REFERENCES

1. *The PEP II Abort Kicker System*, J. de Lamare, etal, PAC97.
2. *Response of Kicker Magnets with Coatings*, Glen Lambertson, PEPII publication AP96.30.
3. *Fast Kickers for SLC*, G.B. Bowden, SLC, Klystron R&D Technical Note, No. 003.